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SURVEYING COST GROWTH

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Cost growth that weapon systems incur throughout their acquisition life cycle concerns those who work in the acquisition environment. One way to reduce the amount of unexpected cost growth is to develop better cost estimates. In attaining better cost estimates though, it is often helpful to understand and account for potential cost drivers. Several cost studies, some of which specifically focus on the aircraft industry, have been performed documenting and investigating these growth factors. Overviews of these various cost growth studies are presented as other tools for the cost estimators and program managers.

The cost growth that major weapon systems incur represents a major management challenge. A 1993 study by RAND cites that by the time a Department of Defense (DoD) Acquisition Category (ACAT) I program completes the production and fielding phase of acquisition, it will experience an average cost growth of approximately 20 percent from its initial estimate (Drezner, Jarvaise, Hess, Hough, & Norton, 1993).

During the early eighties, the Reagan administration recognized two ways to control the problem of cost growth — perform cost/requirements tradeoffs when costs grow and create better estimates (Office of the Under Secretary of Defense, 1981). Since then, high-level DoD management personnel continue to seek better ways of controlling cost growth.

While program managers shoulder the burden of controlling cost growth, the second method promoted by the Reagan administration for addressing cost growth, creating more realistic estimates, pertains more directly to the cost estimating community (Office of the Under Secretary of Defense, 1981). The impediments to creating more realistic estimates primarily stem from the many uncertainties that estimators encounter during their data collection efforts. The Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG) gives guidelines for documenting cost estimating uncertainty for DoD system acquisition programs.

First, they mandate that "areas of cost estimating uncertainty will be identified and quantified" (Department of Defense [DoD], 1992, p. 22). Programs must document this uncertainty in the Cost Analysis Requirements Document (CARD). Second, the CAIG prescribes

"the use of probability distributions or ranges of cost" to quantify uncertainty (DoD, 1992, p. 22). Third, they ask that the uncertainty estimated be "attributable to estimating errors" (DoD, 1992, p. 22). For instance, they list as such examples, performance and weight characteristics, new technology, manufacturing initiatives, inventory objectives, schedules, and financial condition of the contractor.

DoD procedures also provide for contingency estimation and sensitivity analysis, giving the estimator the option to either include or exclude a contingency amount. If the estimator includes contingency amount, he must give the reason for the contingency estimate as well its rationale. In addition, he must "include an assessment of the likelihood that the circumstances requiring the contingency will occur" (DoD, 1992, p. 22).

To better address uncertainty in the estimating process, the defense department sponsors much research. For this article's preparation, we reviewed past growth studies in the literature and highlight those here

Table 1. Consolidated Results of Reviewed Studies

Study	Main Findings
BMDO	• Average RDT&E cost growth is 21%. • Average Production cost growth is 19%. • Only 7 to 16% of programs complete at or below target cost. • Programs with lower dollar value have greater likelihood of cost growth.
RAND	• On average smaller programs have more cost growth. • RDT&E funds tend to experience more cost growth than production funds. • Programs maturity affects cost growth. Longer implies greater likelihood. • New-start programs over modification programs have more cost growth.
NAVAIR	• Cost growth varies across different cohorts (grouped by different estimate categories). • No statistical significance in overall cost growth due to program size. • Acquisition changes since the end of the Cold War have lead to less cost growth. • Cost growth may vary by commodity.
CHRISTENSEN & TEMPLIN	• Management reserve budgets sensitive to contact category (fixed-price higher than cost reimbursable). • MR budgets do not differ between production and RDT&E contracts.
ESKEW	• Weight, speed, production rate, and time explain more than 90 percent of the variation in cost growth of fighter aircraft.
IDA	• Urgency of the program, difficulty of technology, and degree of testing affect cost growth. • A relationship between cost growth and schedule growth in both the development and the production phases exist.
RAND-JSF	• Differences between the competitive and non-competitive development and procurement cost growth factors are not statistically significant.

that we feel provides the cost estimating community with an overall synopsis of available research. We list and explain those in detail in the remaining sections. For ease of review we have summarized their major findings in Table 1.

STUDIES OF COST GROWTH IN DOD ACQUISITIONS

BALLISTIC MISSILE DEFENSE ORGANIZATION STUDY

A recent Ballistic Missile Defense Organization (BMDO) cost growth study provides insight into the nature of cost growth in DoD programs. Using an internal BMDO database of programs (created from a subset of the Selected Acquisition Report [SAR] database), BMDO finds that Research and Development, Test, and Evaluation (RDT&E) cost growth averages 21 percent while that of production averages 19 percent (Coleman, Summerville, DuBois, & Myers, 2000). The study also shows that from 7 to 16 percent of programs complete at or below the target cost. Additionally, data from the study suggests that the lower the dollar value of a program, the greater likelihood of a large cost growth factor. Despite this trend, though, the authors do not provide any statistical tests to explore this possibility.

The BMDO researchers further note that as a program progresses, cost estimators revise their estimates, thereby reducing the amount of estimated risk and increasing the amount of realized risk. Under the assumption of unbiased risk estimates, one expects realized risk to equal estimated risk on average, given a large sample. However, the study shows that the risk portion of the estimate decreases more slowly than the rest of the estimate increases. This evidences a general trend of underestimating risk (Coleman et al., 2000).

RAND STUDY (1993)

The study canvassing an extensive array of information is arguably that of over 100 data points performed by RAND. Like the BMDO study, RAND uses data from the SAR reports, and RAND focuses on the seven categories of cost variance that the SAR contains: quantity, economic, schedule, engineering, estimating, support, and other. In this study, RAND finds that economic and quantity changes have the greatest impact on cost growth. However, RAND excludes them from their study because these two factors are part of the assumptions of a cost estimate initially.

The RAND study goes on to relay several other factors that relate to cost growth. Like the BMDO study, RAND finds an apparent difference in cost growth based on program size. That is, smaller programs have on average more cost growth than larger ones. The RAND researchers postulate as the reason behind this difference the greater level of management scrutiny that higher dollar programs receive. This stands to reason considering more management scrutiny should translate into better cost management.

> **"data from the study suggests that the lower the dollar value of a program, the greater likelihood of a large cost growth factor."**

The authors of the RAND study offer another possible explanation for the difference in cost growth of the smaller programs, "R&D costs are a large portion of total costs and tend to incur more cost growth" (Drezner et al., 1993, p. 49).

In other words, smaller programs are disproportionately smaller in procurement than in RDT&E. Since RDT&E funds tend to experience more cost growth than procurement funds, the same percent RDT&E cost growth in a smaller program pushes the overall program percentage cost growth higher than a large program counterpart.

Program maturity also factors largely in program cost growth. The RAND study notes that "on average, cost growth increases by 2.2 percent per year above inflation because of the effects of maturity" (Drezner et al., 1993, p. 49). RAND emphasizes the importance of these two factors above other factors in the statement, "program size and maturity can dominate other factors affecting cost growth outcomes and so must be considered in both the analysis and the interpretation of results" (Drezner et al., 1993, p. 49).

"While the prototyping probably does significantly reduce risk, it apparently does not reduce it to the extent that would make a prototyped program have less cost growth than a non-prototyped program."

The RAND study elucidates the impact of new-start programs versus modification programs, finding that on average, the new-start programs experience more cost growth than modification programs. The RAND study also finds longer programs to have more cost growth than shorter ones. This relationship proves intuitive: each year brings the opportunity for more cost growth. Interestingly, they find no relationship between planned length and cost growth nor between schedule slip and cost growth (Drezner et al., 1993).

Finally, RAND finds a correlation between prototyping and cost growth:

> We compared the cost outcomes of prototyping and nonprototyping programs, expecting to find that a prototype development strategy contributes to cost control through reduction of uncertainty. Interestingly, programs that included prototyping had a relatively higher cost growth. This result may be due in part to the timing of the prototype phase within the context of the overall program schedule, since earlier prototyping makes data available earlier, thus potentially affecting the baseline cost estimate at the time of EMD start. Our results are consistent with this notion. It may also be true that prototyping was conducted for programs with relatively higher degrees of technical uncertainty, a hypothesis that deserves further exploration. (Drezner et al., 1993, p. 51)

Given that DoD prescribes risk reduction such as prototyping for riskier programs, RAND's assessment rings true. While the prototyping probably does significantly reduce risk, it apparently does not reduce it to the extent that would make a prototyped program have less cost growth than a non-prototyped program.

NAVAIR Study

Naval Air Systems Command (NAVAIR) presents its most recent study on cost growth at the 2001 DoD Cost Analysis Symposium, corroborating some of the results of previous studies.

Here again, SAR data are used. As part of their analysis, they explore the possible need for "cohort tracking" when analyzing cost growth (Dameron, Pullen, Summerville, Coleman, & Snead, 2001).

By *cohort tracking*, the NAVAIR team refers to the grouping of cost growth according to certain programmatic characteristics that relate to common patterns of cost growth. The team divides program cost growth into five categories or cohorts — RDT&E cost growth for programs with a planning estimate (PE) and a development estimate (DE); RDT&E cost growth for programs with a DE only; procurement cost growth for programs with a PE, a DE, and a production estimate (PdE); procurement cost growth for programs with a DE and a PdE only; and procurement cost growth for programs with a DE only (Dameron et al., 2001).

The three different estimates (PE, DE, and PdE) are the baseline estimates that correspond to each of the major decision points in Milestone A, B, and C respectively. NAVAIR uses the five cohorts consisting of the different types of estimates to categorize the cost growth, because the use of those mixes of cost estimates relate to different types of program structures, which might represent distinct populations with distinct cost growth patterns.

After looking at 318 DoD programs, the cohort study results show that the PE and DE cohort has an average of 30 percent RDT&E cost growth; the DE-only cohort has an average of 25 percent RDT&E cost growth; the PE, DE, and PdE cohort has an average of 35 percent procurement cost growth; the DE and PdE cohort has an average of 25 percent procurement cost growth; and the DE-only cohort has an average of 15 percent procurement cost growth. The sample sizes are 25, 140, 6, 53, and 94 respectively (Dameron et al., 2001). The NAVAIR group indicates that the "results are tentative," but their findings suggest differences in cost growth from one cohort to another.

In particular, they point out that, in their study, "programs with a Program Definition and Risk Reduction (PDRR) phase have more growth" (Dameron et al., 2001, p. 11). The purpose of PDRR is to reduce risk, so programs with PDRR naturally have a lot of uncertainty, and quantifying the costs of such a program should be more difficult than for less risky programs. In addition, the natural correlation between programs with a PDRR phase and programs with a prototyping effort, leads one to expect similar results as the two relate to cost growth. Finally, programs with a PDRR phase tend to have a longer RDT&E funding year stream than those without PDRR. This meshes with RAND's finding that longer programs tend to have higher cost growth. Thus, consistency exists in the findings showing that programs with risk reduction efforts tend toward higher cost growth.

"By *cohort tracking*, the NAVAIR team refers to the grouping of cost growth according to certain programmatic characteristics that relate to common patterns of cost growth."

The NAVAIR study also analyzes cost growth correlations between program phases and between the RDT&E and procurement appropriations. The study finds a significant correlation between RDT&E cost growth in the PDRR phase

and RDT&E cost growth in the EMD phase and also finds "significant correlation between procurement growth during the EMD and production phases" (Dameron et al., 2001, p. 14). Finally, the study uncovers a significant correlation between appropriations such that, during EMD, when the RDT&E appropriation experiences cost growth, so does the procurement appropriation (Dameron et al., 2001).

As a third area of study, the NAVAIR group analyzes how program size affects cost growth. Unlike the BMDO and RAND studies, the NAVAIR team performs statistical comparisons that reveal that high and low dollar programs have identical distributions despite "a trend of more high end extrema in the smaller size classes" (Dameron et al., 2001, p. 21). To explain the difference in the extrema, they reason that, "high risk programs may be terminated earlier if large, but tolerated if small" (Dameron et al., 2001, p. 21). Thus, inferential statistics suggests no difference in the overall cost growth based on size.

"NAVAIR's results suggest that acquisition changes since the end of the Cold War lead to less cost growth."

Next, NAVAIR studies the effects of the era in which an acquisition terminates. The team uses "DoD programs with DE only from the RAND 93 dataset, NAVAIR programs with DE only from the SAR 00 dataset, and NAVAIR programs with DE only from the Contract dataset (RDT&E only)" (Dameron et al., 2001, p. 23). Thus, they use three separate data sets, two of their own compilation and the RAND 93 dataset. The group studies the effects of two eras — pre–1986 and post–1986. They choose 1986 as a dividing point, because that year marks the last year of the Reagan arms buildup (Dameron et al., 2001). The team performs *t*-tests to determine if the two eras differ statistically. They find the following results:

- RAND 93: The means of programs through 1986 and those after 1986 did show a statistical difference for RDT&E, but not for procurement.

- SAR 00: The means of programs through 1986 and those after 1986 did show a statistical difference for procurement, but not for RDT&E.

- Contract: The means of programs through 1986 and those after 1986 did not show a statistical difference for RDT&E. (Dameron et al., 2001, p. 31)

The team concludes that their "analysis supports a decline in cost growth factor (CGF) over time" (Dameron et al., 2001, p. 32). They mention that these results differ from previous studies perhaps because of differences in the number of data points or dates of era division (Dameron et al., 2001).

NAVAIR's results suggest that acquisition changes since the end of the Cold War lead to less cost growth. Although difficult to pinpoint the reason for this decline in cost growth, logic leads to candidate scenarios. The draw-down in military spending after the Cold War produces an environment in the government where meeting cost goals becomes more important for program survival. So perhaps the ensuing emphasis on better estimating improves base-line estimates from which cost growth is measured.

Improvements in the estimating profession might also play a part in improving base-line estimates.

NAVAIR also studies differences between commodities and their relation to cost growth. The team looks at all three databases, but limits the data to 20 RAND 93 programs, 11 SAR 00 programs, and 21 contract data programs. They conclude that missile programs experience higher cost growth during RDT&E than either electronic or aircraft programs. This result suggests that cost growth may vary by commodity.

The NAVAIR team further compares RDT&E cost growth in small programs (less than one billion dollars in RDT&E) as portrayed through the SAR 2000 data versus the NAVAIR contract database. Their analysis shows that the results from the two databases do not significantly differ (Dameron et al., 2001). They conclude that potential exists to use either database to study cost growth. Intuitively, cost growth from a contract only perspective mirrors that of an overall program cost perspective, because the vast majority of program dollars apply to contracts.

CHRISTENSEN AND TEMPLIN STUDY

David Christensen and Carl Templin research cost growth using the Defense Acquisition Executive Summary (DAES) database and arrive at potentially useful findings in the search for predictors of cost growth. The DAES database contains contractor information organized according to the rules of Earned Value Management, a process by which the government monitors the cost and schedule performance of contracts against baseline figures (Christensen & Templin, 2000).

The researchers consider "hundreds of DoD defense acquisition contracts from 1975 through 1998" in a hypothesis testing scenario focused on the nature of management reserve (MR) budgets (Christensen & Templin, 2000). DoD characterizes an MR budget as "a reserve for uncertainties related to in-scope but unforeseen work" (DoD, 1997, p. 12). MR budgets, because they represent the contractors' assessment of risk for acquisition programs, can provide useful insight into the overall risk assessment that DoD uses in its budgeting process.

Christensen and Templin recognize that many factors affect the development of a contractor's MR budget, and that the "achievability of a budget depends on how the budgets are established" (Christensen & Templin, 2000, p. 195). Thus, overruns can vary depending on factors such as differing methods, abilities, and motivations of those who set the MR budgets (Christensen & Templin, 2000). A 1998 survey of 300 DoD risk analysis professionals (U.S. Aerospace Cost Risk Analysis Survey, 2000) supports this statement by displaying the following variety of perspectives on risk analysis extant within government and contractor circles.

"They [the team] conclude that missile programs experience higher cost growth during RDT&E than either electronic or aircraft programs."

- 27 percent of analyses perform the risk assessment separately from the cost estimate.

- 26 percent of program managers do not accept risk assessment at all, not even *slightly*.
- 32 percent of the risk assessments do not involve finance or estimating.
- 38 percent of cost risk analysts have received no training, either formal or informal.
- 44 percent of risk ranges are intuitive judgments, without historical data or guided-survey.
- 69 percent of variable distributions are triangular.
- 18 percent of unfavorable assessments are ignored, as managers *stay the course*.

In addition, Christensen and Templin (2000) note that contractors should provide greater MR budgets for riskier projects. The authors characterize the development phase of acquisition as more uncertain than the production phase, and they characterize price contracts as more uncertain than cost-reimbursement contracts (Christensen & Templin, 2000). From this awareness of the diversity of risk analysis, Christensen and Templin perform hypotheses testing to realize the following results:

> The amount of an MR budget is sensitive to contract category (cost-reimbursable versus fixed-price), and the managing service. With regard to contract category, the median MR percent on fixed-price contracts is significantly greater than the median MR percent on cost reimbursable contracts. This is consistent with the expectation that contracts with more risk to the contractor have a larger MR budget. We do not know why MR budgets differ across the three services. Possible explanatory factors include differences in the weapon systems purchased by each service, and the contractors that build the systems. (Christensen & Templin, 2000, p. 204)

With regard to the acquisition phase, the researchers do not find that the MR budget differs between production and RDT&E contracts (Christensen & Templin, 2000). Christensen and Templin (2000) shed light into the way that contractors manage risk through MR budgets. The relationship between contract type and the MR budget stands to reason, since certain contract types place more risk on the contractor than others. The MR budget insensitivity to acquisition phase differs from the government's perspective that RDT&E efforts are more risky than procurement efforts; this difference reemphasizes the importance of using contract type to instigate contractor behavior that best advances government objectives. The sensitivity to managing service proves enigmatic. While possible that significant differences exist in the way each service manages its contracts, it may be that some other variable or variables, highly correlated with managing service triggers this sensitivity.

Cost Growth Specific to the Aerospace Industry

Eskew Study

To find the true rate of cost growth of fighter aircraft over time, Henry Eskew runs a multiple linear regression of 17 tactical aircraft from 1950 through 1980 (Eskew, 2000). He normalizes his data for production quantity by using the estimated 100th production unit cost, and he normalizes his data for inflation by applying the appropriate DoD inflation indices to convert his data to constant year (CY) 1990. Using the logarithm of cost as his response variable, he finds weight, speed, production rate, and time as statistically significant predictor variables that explain "more than 90 percent of the variation in cost" (Eskew, 2000, pp. 211–212). He also determines that, as a sole predictor, time explains about 40 percent of the cost variation (Eskew, 2000).

Although useful as a literature review, one must note some limitation of the Eskew study's applicability. First, the study looks at a limited amount of data from a limited perspective. It only considers tactical aircraft in its search for predictors, and it only has 17 data points. In addition, this research lacks currency, spanning the period from 1950 through 1980, and seeks to explain cost growth as overall increases in unit cost measured from previous programs over time (Eskew, 2000). Most of the research we consider heretofore considers cost growth within a single program over a much shorter time period.

Dr. Eskew (2000) seeks to dispel the myth that "no systematic relationship exists between the characteristics of an aircraft program and the length of its development cycle" (Eskew, 2000, p. 210). He uses the same normalization techniques mentioned earlier for inflation and quantity; however, he includes different aircraft, adding non-tactical fixed wing aircraft, and removing non-fixed wing aircraft (Eskew, 2000). The results of his 17 data-point regression show that unit flyaway cost predicts approximately 60 percent of the variance in the length of the development program: this predictive ability increases to 70 percent when a dummy variable is added indicating whether or not a program has inherited a significant amount of technology from a previous program (Eskew, 2000). Overall, the Eskew study highlights a correlation between aircraft physical and functional characteristics and production costs, and between program schedule and production costs.

> **"Overall, the Eskew study highlights a correlation between aircraft physical and functional characteristics and production costs, and between program schedule and production costs."**

IDA Study

The Institute for Defense Analyses (IDA) performs an analysis on cost and schedule growth of tactical missiles and tactical aircraft in 1994 with the goal of finding patterns of cost growth and the reasons for the cost growth (Tyson, Harmon, & Utech, 1994). Within the group of 20 tactical missiles investigated, the IDA group finds that only two stay within their schedule, with one program slipping by as much as 180 percent. They also find that only two programs stay within budget, while the two

worst performers exceed their budgets by a factor of two (Tyson et al., 1994). The researchers of IDA examine the characteristics of the programs with the highest and lowest schedule and cost growth. From their study, they find that:

> [Missile] programs that employed a high degree of concurrency, that had to be dual-sourced for technical reasons or that were dual-sourced at less than full rate, had high cost growth. In one case, the threat of competition appeared to reduce costs. (Tyson et al., 1994, p. S-2)

The results from aircraft programs do not vary as much. The authors suggest closer management scrutiny and "protection from schedule stretch" as reasons for the more consistent cost growth in aircraft programs (Tyson et al., 1994, p. S-2). Two aircraft programs suffer elongated production schedules, but do not experience high production cost growth. The authors theorize that generally extending production incites cost growth; however, in these cases the existence of other DoD contracts cushions the impact of the adjusted schedules. The authors identify the F/A-18 as the program with the highest cost growth. They theorize that late engineering changes incite the high cost growth (Tyson et al., 1994).

The study considers whether modification programs have lower cost growth than new start programs. The one aircraft in their sample that is a modification does in fact experience low cost growth. The team finds that missile modification programs vary greatly in the cost growth they experience. They cite the fact that most missile modifications affect the expensive guidance and control system of the missile as a possible reason for this inconsistency (Tyson et al., 1994).

The researchers further find that the urgency of the program, the difficulty of the technology, the amount of concurrency, and the degree of testing all seem to affect cost growth (Tyson et al., 1994). From these results, the IDA researchers discover a relationship between cost growth and schedule growth in both the development and the production phases (Tyson et al., 1994). They find that quantity increases during development largely drive development schedule growth. The authors mention "the need to produce more items for testing than planned" as the reason for the increase in quantity (Tyson et al., 1994, p. S-6).

It is not clear whether failed tests drive the need to produce more test units or simply uncertainty in the planning process drove the need to produce more test units. Either way, one can draw a link back to technical risk from the need for more test units. The study also finds that whether a missile is an intercept missile and the length of the original schedule prove useful predictors of development schedule growth.

Lastly, the IDA study adds depth to the study of cost growth by using multiple regression to arrive at predictive formulas. Using multiple regression brings with it the benefit of taking into account the multi-dimensional interactions that independent variables have with dependent variables that can prove misleading in simple linear regression analysis and hypothesis testing.

RAND Study (2001)

In support of the Joint Strike Fighter (JSF) program, RAND studies the effect of competition on the amount of cost growth that occurs in both the RDT&E and procurement budgets (Birkler, Graser, Arena, Cook, Lee, & Lorell, 2001). The researchers analyze 14 programs that use competitive strategies and 44 programs that do not (Birkler et al., 2001). They find that "the results are mixed and the differences between the competitive and noncompetitive development [and procurement] cost growth factors…are not statistically significant at the 10-percent level" (Birkler et al., 2001, p. 80).

These results are potentially misleading, however, in that they represent a program-wide look, rather than a study of individual contracts. In other words, a program might be competitively awarded initially, but at a certain point in the string of contracts that make up a program one can make the case that a competitive environment no longer exists. Perhaps a study that compared individual contracts (rather than entire programs) might exact different results.

Conclusion

In this article, we document many studies that query different databases using various statistical methods in the effort to explain cost growth in DoD acquisition. We consider studies of overall DoD acquisition as well as studies that focus on a particular industry within the DoD acquisition landscape. Further research is currently being conducted to examine/investigate how best to model cost growth and which predictor variables should be included in such a model. From these, appropriate statistical tools and methodologies could then be made available to the cost community.

This article applies not just to the cost estimator, but also to the entire integrated process team. Knowledge of these studies should bring to bear a better understanding, a sharper focus, and a more efficient approach to those who seek to study cost growth in the future. It should also be clear to the estimator that more often than not, estimates will be low. From the many studies in this article, the estimator should find some insight that will lead him to a better analysis of risk to compensate in part for that tendency to underestimate. For the rest of the integrated process team, the reality is that cost overruns can kill programs.

As mentioned in the beginning of this article, the two sides of the solution coin are: more realistic baseline estimate (with accompanying risk dollars) and better cost control. Many hindrances might stand in the way of achieving more realistic estimates and better cost control. Those hindrances might be in the form of priority setting, manpower shortages, lack of training, budget cuts, requirement creep, or any number of other issues both foreseen or unforeseen. This article focused on providing decision makers in the acquisition world with some historical insight into what research has been done regarding cost growth. With knowing what has been in the past, it provides a roadmap to prevent rework as well as fine tune future research and promote ready-to-use analytical tools.

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